Appendix 6.1
Monitor Well Construction and Installation

A.6.1.1 Introduction

Monitor wells are installed to collect groundwater quality data, hydrologic information and determine ground water flow direction. They can be installed either permanently or temporarily. The types of wells used for remedial investigations include Category 3 Resource Evaluation Wells which include monitoring wells, air-sparging wells, soil vapor extraction (SVE) wells, recovery wells and temporary wells installed for environmental remediation projects (see N.J.A.C. 7:9D-2.1(a)3). Category 5 Geotechnical Wells include test borings, probe holes and borings involving use of direct-push methods (see N.J.A.C. 7:9D-2.1(a)5).

Their method of installation and construction can greatly impact the quality of ground water samples collected from them. For example, temporary wells that are driven or pushed do not always have filter packs, which may result in samples with high turbidity levels. This artifact would have to take this into consideration if samples are to be collected for metals analysis. The following text describes different methods of well drilling and monitor well construction with considerations for their use and possible impacts on ground water samples. All wells must be installed by a New Jersey-licensed well driller of the appropriate class, pursuant to N.J.A.C. 7:9D. Prior to installing a well, the well driller must obtain a well drilling permit from the Bureau of Water Allocation (BWA, 609-292-2957), pursuant to N.J.A.C. 7:9D-1.11. Within 90 days of completing a well, the well driller must submit a well record to BWA, pursuant to N.J.A.C. 7:9D-1.15.

The drilling methods described below also are applicable to the collection of subsurface soil samples. Profiles of subsurface conditions encountered and well installation details must be recorded on logs, preferably by a qualified geologist and submitted with the completed well record to the Bureau of Water Allocation. The information recorded must include that specified at N.J.A.C. 7:26E-3.6(a)2, at a minimum, and should be consistent with applicable standard protocols including those of the American Society for Testing and Materials (ASTM). See also Section 6.2.3, *Soil Log* and Section 6.2.3.5, *Soil Classification.*

A.6.1.2 Conventional Well Drilling Methods

A.6.1.2.1 Hollow-Stem Augers (HSAs)

Wells can be installed in unconsolidated formations using solid-stem or hollow-stem augers (HSAs). The augers are advanced by rotation and the drill cuttings are brought to the surface by travelling up the outside of the auger flights in a screw-like manner. HSAs have the advantage of allowing the well to be installed inside the hollow stem of the auger, which prevents the borehole from collapsing. Upon reaching the planned well depth, the casing and screen are placed inside the HSAs and the flights are individually removed while the annular space around the well is filled with the filter pack and grout, as appropriate. Conversely, solid-stem augers must be completely removed from the borehole before well installation, which can lead to collapse of the borehole. For this reason, solid stem augers are seldom used for installation of monitor wells.

HSAs come in a variety of sizes and allow collection of soil samples utilizing split spoons or Shelby tubes. Samples are collected ahead of the augers for determining soil/sediment type, stratigraphy, the depth to the water table and for collecting soil samples for chemical analysis. During this process, the standard penetration test (SPT, ASTM Method D 1586) can also be performed. The HSA method also has an advantage over mud-rotary drilling techniques in that drilling mud is not used. Drilling mud can contaminate the soil samples or and potentially reduce the yield of the wells.

A disadvantage of the method is that HSAs cannot be used to drill into competent bedrock or through large boulders. Also, “heaving or running sands” can be forced up inside the augers as a result of strong vertical groundwater gradients, which can hamper efforts to collect soil samples or complete well installation. Furthermore, the maximum depth achievable using HSAs, which is generally shallower than other methods is dependent not only on the ability of the rig (e.g., horse-power, rig-torque, weight of augers etc.) but also the lithology of the material drilled.

A.6.1.2.2 Rotary Drilling

Rotary drilling methods include direct rotary and reverse-circulation rotary. Direct rotary is more commonly used in environmental investigations whereas reverse-circulation rotary is used in drilling large-diameter water supply wells. In direct rotary drilling the borehole is advanced by rotating the drill pipe (rods) and bit to produce a cutting action. The cuttings are removed from the borehole by continuous circulation of a drilling fluid. The fluid or “mud” is pumped down the inside of the drill pipe and is circulated back to the surface on the outside of the pipe. The fluid removes the drill cuttings from the borehole and cools and lubricates the bit. Mud used during direct rotary consists of additives (e.g., bentonite) water or air.

Reverse-circulation rotary drilling is similar to direct rotary except the drill rigs are larger and the flow of the drilling fluid is reversed. The drilling fluid moves upward inside the drill pipes and circulates back to the borehole via settling pits. The drilling fluid returns to the borehole via gravity and moves downward in the annular space between the drill pipe and borehole wall. Drilling fluids for reverse circulation rotary are generally water and any suspended particles picked up from the surrounding formations

Mud-rotary methods can be used to drill in both unconsolidated and consolidated (bedrock) formations. In addition, drilling mud stabilizes the borehole and limits the potential for borehole collapse. Disadvantages of using the mud-rotary method include the difficulty in determining the depth to the water table, the potential for drilling mud to impact soil samples and dragging of contamination into deeper zones since the drill cuttings are re-circulated in the borehole. Wells installed using this method typically take longer to develop (see below) than wells installed using the HSA or air-rotary methods due to the invasion of mud filtrate into the formation.

In air-rotary drilling, compressed air is directed down the inside of the drill pipe. As in mud-rotary drilling, air removes the cuttings and lubricates the bit. However, since air has no viscosity, it cannot be used to stabilize a borehole therefore, casing must be advanced in unconsolidated formations to keep the borehole open. This is why air rotary methods are best suited for drilling in bedrock formations. The percussion-type air-rotary “hammer” bit provides the best penetration rate when drilling bedrock consisting of crystalline rock. However, when drilling above the water table, an air-rotary bit can grind the soil and bedrock to a fine powder which is blown out of the hole with air and which has the potential to be inhaled. Therefore, drilling above the water table using air-rotary methods requires the addition of potable water to the borehole for dust control. In addition, the air compressor should be of the oil-less variety or have a filter to prevent any oil from entering the borehole.

A disadvantage of using rotary methods while drilling in unconsolidated formations is the require-ment of pulling the drill pipe out of the hole each time that a split-spoon soil sample is collected (and the SPT is performed). This can add up to a considerable amount of time when deep wells are being installed or when continuous split-spoon sampling is being performed. As stated above, split spoons used to collect soil samples can become contaminated when they are advanced down a mud-filled borehole.

A special type of rotary drilling is bedrock coring, wherein a special core bit and barrel are used to retrieve relatively undisturbed core samples of the bedrock. Coring allows better characterization of bedrock lithology and other features including orientation of fractures and bedding planes, which can control contaminant migration. Core barrels can either be unoriented or oriented. An oriented core is scribed with respect to magnetic north. Although more expensive than collecting an unoriented core, this method gives the true orientation of the features encountered in the core. Logging of rock core should be consistent with N.J.A.C. 7:26E-4.4(g)5. See the section on coring in Chapter 6, Section 6.3.4, *Core Logging*.

A.6.1.2.3 Drilling Fluids

Drilling fluids are generally air (air-rotary) or bentonite and/or water (mud-rotary). Water added to a borehole must be of potable quality. The source of the potable water used during the installation (and development) of monitor wells should be documented (e.g., in the Remedial Investigation Report).

Bentonite is high swelling clay with sodium montmorillonite as its primary clay mineral. Bentonite is added to water to increase the viscosity of the drilling fluid so that drill cuttings can be removed from the borehole more effectively. At the same time, the viscosity must be low enough to allow cuttings and coarse-grained particles to settle out once they are circulated out of the hole. Bentonite also adds weight to the drilling fluid, which helps to maintain borehole stability.

While all drilling fluids have the potential to impact groundwater quality to some extent, the use of polymer-based drilling muds (e.g., Revert®) can significantly impact the quality of water samples collected from wells. Biologic activity related to the decomposition of these compounds can cause a long-term variation in the quality of the water sampled from the well (EPA, 1991, and Barcelona, 1983). Therefore, use of polymer-based drilling muds is not acceptable unless specific approval is first obtained from the SRP case/site manager or geologist.

A.6.1.3 Specialized Drilling Methods

A.6.1.3.1 Sonic Drilling

A resurrected and fastly becoming popular drilling technology used in the environmental field is sonic drilling, which is sometimes called rotosonic drilling. The method involves driving a core barrel using vibration, rotation and a downward force to collect soil samples. A sonic drill rig looks and operates very much like a conventional top-drive rotary or auger rig. The main difference is that a sonic drill rig has a specially designed, hydraulically powered drill head or oscillator, which generates adjustable high-frequency vibrational forces. The oscillator uses two eccentric, counter-rotating balance weights or rollers that are timed to direct 100 percent of the vibrational energy at 0 degrees and 180 degrees. There is an air spring system in the drill head that insulates or separates the vibration from the drill rig itself. The sonic head is attached directly to the drill pipe or outer casing, sending the high-frequency vibrations down through the drill pipe to the bit.

A core barrel is advanced using vibration, rotation, and downward force to collect continuous soil cores up to 20 feet in length. The bit at the end of the core barrel contains carbide teeth allowing the core barrel to be advanced through most overburden, soft bedrock, and minor obstructions such as bricks and boulders. Once the core barrel has been advanced, a secondary or “over-ride “ casing is advanced down to the same depth as the inner core barrel. The over-ride casing keeps the borehole from collapsing while the inner core barrel is removed. Once the core barrel is removed, the soil core is pushed out of the core barrel through the use of vibration and either air or water pressure. Soil core diameters are dependent on the size of core barrel used and range from 3 to 12 inches. The use of multiple over-ride casings of increasing diameter allow the borehole to be telescoped down through multiple confining units. Continuous soil cores to over 400 feet have already been installed in New Jersey using this method. The setup used in sonic drilling makes this drilling method amendable to collecting soil cores and installing wells in angled boreholes. With only the bottom of the inner and outer core barrel exposed to the aquifer at any given time, determining the location of the water table can be difficult.

When using this drilling method to collect soil cores that will be used to obtain soil samples for VOC or SVOC analysis, two issues of concern must be addressed: heating of the soil core during drilling, and disturbance of the core during drilling, extraction and handling.

While this drilling method has the capability of drilling through and providing samples of coarse gravels, boulders and tight clays, these situations will result in slow drilling or advancement of the core barrel. The result is a hotter core barrel and a longer contact time between the core barrel and the encased soil core. The aforementioned conditions will increase the probability that the sonic method will raise the temperature of the soil core and facilitate VOC and SVOC loss. If heating of the soil core is a concern, the following procedures should be implemented:

- Collect soil cores in shorter runs. While some sonic rigs have the capability of collecting 20 feet of soil core at a time, the process of collecting the longer core results in the core being in contact with the core barrel for a longer period of time and consequently absorbing more heat from the core barrel itself.
- Add water between the inner core barrel and the outer override casing. This water would reduce friction and adsorb heat between the inner core barrel and the outer over ride casing.
- Maximize drilling advance rate. The faster the core barrel is advanced, the less likely the core barrel will heat up, and the less contact time the soil core has with the core barrel. Drilling with a 3-inch diameter core barrel and a 5-inch diameter override casing, instead of the standard 4-inch core barrel and 6-inch over ride casing, may increase advance rates and reduce the potential for soil core heating. If a significant decrease in drilling advance rate is observed, stop drilling and remove what soil core has accumulated in the core barrel. Resume drilling through the resistant material (gravel, boulder, hard clay, etc.). When the resistant material has been penetrated and the drilling advance rate increases, stop drilling and remove what material has accumulated in the core barrel. Wash down the core barrel with cool water to cool the core barrel and associated casing, and resume drilling.

Disturbance of the soil core is most likely to occur during removal of the soil core from the core barrel. The soil cores are usually vibrated out of the core barrel into plastic bags approximately 5 feet in length. As the plastic bags are a little larger than the soil core itself, fragmentation of the soil core may occur as the core is extruded into the bag or while the bagged core is being moved in an unsupported manner. Soil conditions that are prone to disturbance include wet or dry zones that contain little or no fines, and well graded sands that contain significant volumes of water.

If integrity of the soil core is of concern, the following procedures should be implemented:

- Measures should be taken to ensure that the core, from the time it is extruded from the core barrel, is rigidly supported through the use of some type of cradle or carrying device.
- The core should not be removed from its cradle until all sampling of the core has been completed. Acrylic liners are available for some core sizes and can be used to hold the core together upon removal from the core barrel.

- If the soil is to be sampled for VOCs, acrylic liners must be used.

Sonic drilling has been approved for:

- geologic profiling through the production of soil cores;
- collection of insitu ground water grab samples during borehole installation;
- well installation and;
- sampling of the soil core for metals, PCBs, and pesticides.

Sampling of the soil core for VOCs or SVOCs must be approved on a case by case basis. Proposals for VOC or SVOC soil core sampling must include provisions to minimize core fragmentation and heat generation, such as:

- the use of acetate liners in the core barrel so that the soil core does not have to be extruded out of the core barrel;
- limiting the length of soil core generated during a given downhole run and;
- implementing practices to reduce the residency time of the soil core in the core barrel. For the analysis of SVOCs, the use of the acetate liners is not required.

The large diameter of the core barrel enables ground water sampling equipment to be placed inside the core barrel so that discrete depth groundwater samples can be collected during borehole advancement. If a well is to be installed in the borehole, the sandpack and grout are placed as the core-barrel and over-ride casing(s) are selectively vibrated out of the ground. The vibratory action reportedly facilitates the settlement of the sandpack and grout. Upon completion, no casing is left in the ground other than the well casing and screen.

Another application of the sonic method involves vibratory direct push installation of monitor wells without drilling a borehole. However, knowledge of the local stratigraphy (depth of confining layers, etc.) and depth to water should be known before the wells are installed. Therefore, soil sampling using sonic methods or other, conventional, methods (e.g., split-spoon sampling) should be performed prior to installing wells using the sonic method. This method does not allow or require installation of filter pack and grout filling of annular space. Approval to install wells in this manner should first be obtained from the SRP case/site manager or geologist.

The ability to quickly install deep borings and wells, while generating a large-diameter continuous soil core, makes this drilling technique invaluable when continuous soil sampling is needed to assess deep or complex geological situations. However, sonic drilling's high cost, relative to other drilling methods, may be prohibitive for small projects or shallow boreholes. The higher cost of the drilling method should be weighed against the cost savings incurred due to its faster drilling rate and high quality of the soil core produced.

A.6.1.3.2 ODEX® Method

In situations where boreholes cannot be stabilized, conventional drilling methods may not be adequate for drilling soil borings or installing monitor wells. In these situations, the ODEX® method can be used to simultaneously drill and case a borehole. This method involves use of an eccentric bit, along with a conventional rotary hammer, to drill a borehole of slightly larger diameter than the casing (See Figure 6.10). The bit retracts to allow its passage through the casing. Once below the casing, the bit is expanded and used to drill a slightly larger borehole. The bit can be retracted and retrieved through the casing to allow collection of soil and/or rock samples.

A disadvantage of the method is the fact that installation of the casing is only temporary. (The Department does not allow installation of permanent casing in monitor wells using this method.) It

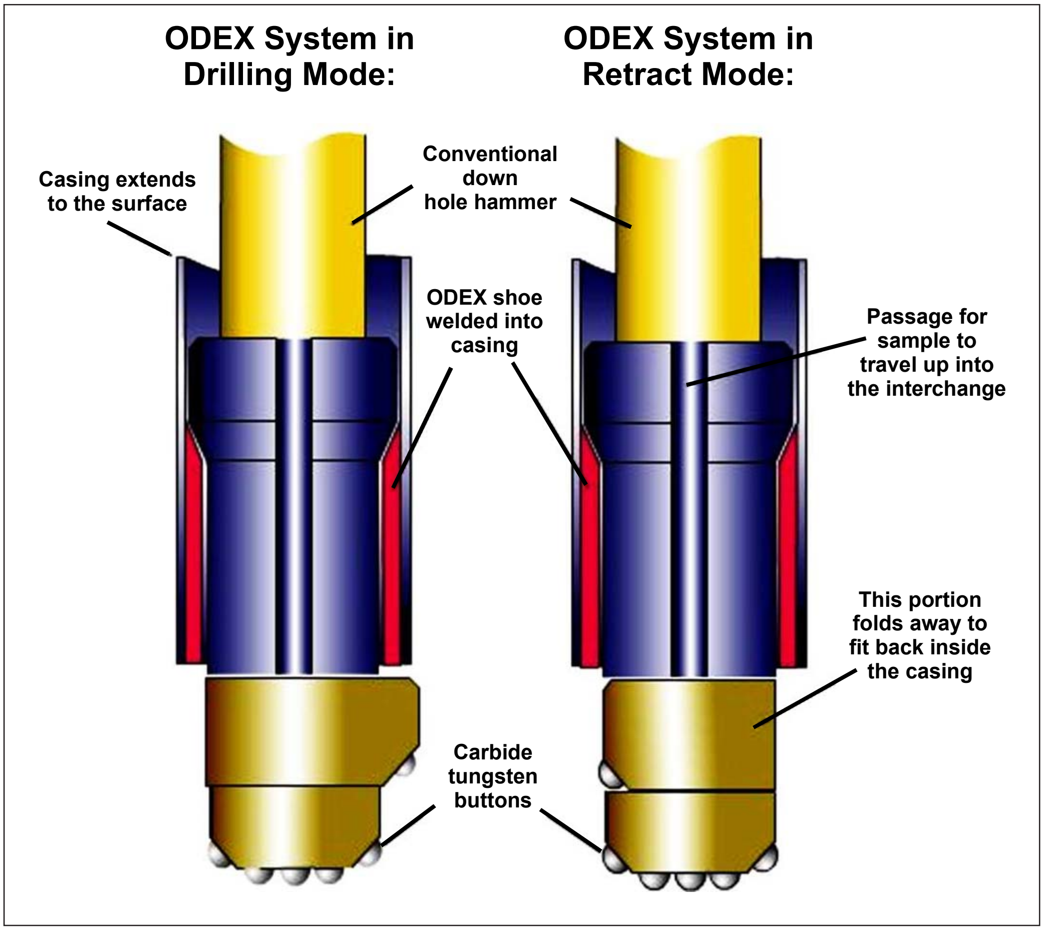

Figure 6.10 ODEX® System. Source: http://www.midnightsundrilling.com/ODEX_system.html

cannot be grouted in place. This means that conventional methods must be used to install and grout outer casing when installing monitor wells in confined aquifers. Another disadvantage of the method is the potential for rock cuttings to jam the bit and not allow it to be retracted and, therefore, retrieved through the casing.

A.6.1.3.3. Direct-Push Drilling

Direct-push technology was first developed in the geotechnical industry using cone penetrometer testing (CPT) methods to obtain information on soil/sediment type, stratigraphy and the depth to groundwater without collecting actual soil samples and installing monitor wells. The method involves pushing rods into the subsurface under a constant weight while recording such parameters as sleeve friction stress, tip stress and pore pressure. The method has been expanded in the environmental industry to include the investigation for hydrocarbons (e.g., the fuel fluorescence detector or FFD® developed by Handex and the Laser Induced Fluorescence (LIF) Probe used in the SCAPS system), and natural gamma and resistivity logging tools. These methods provide only screening-level data quality. However, they allow the collection of numerous data points in one mobilization without generating any soil cuttings, which would otherwise have to be characterized and disposed of.

A variation of the method involves hydraulically pushing hollow rods into the subsurface for the purpose of collecting soil and/or groundwater samples (e.g., Geoprobe®). The method can be used to install small-diameter wells used to collect groundwater samples. These wells are usually installed for temporary use and subsequently retrieved. (i.e., Category 5 *Geotechnical Wells*). Wells installed to a depth of 50 feet or less and that remain in place 48 hours or less do not require boring permits. Wells installed to depths greater than 50 feet or that remain in place longer than 48 (i.e., Category 3 *Resource Evaluation Wells*) hours require well drilling permits and completion of well abandonment reports when decommissioned; these wells must be decommissioned using an approved grout material.

Advantages of the direct-push method include the relatively quick collection of groundwater samples and, when used along with a mobile laboratory, collection of data in "real" time. The method allows for collection of multiple samples in a day with the potential for achieving contaminant delineation in one mobilization of the field equipment. The data can also be used to select locations of permanent monitor wells.

Disadvantages of the method include the fact that the data quality achieved are often suitable only for screening purposes. Direct-push methods typically result in very turbid samples since an oversize borehole is not produced and a filter pack is not used. Turbid samples can produce higher metals concentrations in groundwater samples since metals are typically adsorbed onto soil particles. Use of direct-push methods can also cause cross-contamination since contamination from shallow zones may be driven down to deeper zones. Due to the narrow diameter of the direct-push rods, samples are often collected with peristaltic pumps. When samples are collected for volatile organic compounds (VOCs) using peristaltic pumps, some of the volatiles may be lost due to the pressure drop produced by the suction lift. In such cases, the VOC data must be qualified accordingly. For this reason, use of the peristaltic pump for collecting groundwater samples for VOC analysis is not recommended and approval for its use should first be obtained from the SRP case/site manager or geologist.

Another disadvantage of using direct-push technology for collecting groundwater samples is the potential to breech confining units. To prevent this, soil sampling using direct-push technology or conventional split-spoon sampling techniques should first be performed to identify the presence, depth and lateral extent of confining units. Pushing through confining units should be avoided if the presence of dense, non-aqueous-phase liquid (DNAPL) or very soluble compounds such as MTBE are suspected or the contaminant plume appears to be diving in the aquifer.

For additional information on well drilling methods, please refer to the, *Handbook of Suggested Practices for the Design and Installation of Ground-Water Monitoring Wells*, (EPA, 1991).

A.6.1.4 Monitor Well Design And Construction Considerations

Well construction specifications for unconsolidated, confined and bedrock aquifers are provided in this Appendix. As provided in N.J.A.C. 7:9D, most wells used in the investigation of contaminated sites are Category 3 wells (resource evaluation wells including monitoring wells, air sparging wells, soil vapor extraction wells, recovery wells, and wells or well points installed for environmental projects) and Category 5 wells (geotechnical borings including test borings, probe holes and those involving direct-push technologies). Requirements for the construction and maintenance of all Category 3 wells are provided at N.J.A.C. 7:9D-2.4. Specific requirements for the installation of Category 5 geotechnical borings are provided at N.J.A.C. 7:9D-2.6. Any proposed deviations from these construction standards must be approved by the BWA, pursuant to N.J.A.C. 7:9D-2.8.

The following is a discussion of different aspects of monitor well construction.

A.6.1.4.1 Well Diameter

Well construction varies depending on the intended use of the wells. Most permanent, overburden monitor wells are constructed of two-inch- or four-inch-diameter polyvinyl chloride (PVC) or stainless steel, as most sampling devices can easily accommodate these diameters. For wells used to extract groundwater (e.g., recovery wells), well diameters may need to be larger (e.g., six inches or greater) to accommodate submersible pumps.

The Site Remediation Program does not ordinarily allow use of permanent monitor wells with a diameter of less than two inches unless they are used for the sole purpose of obtaining water-level measurements (i.e., piezometers). The use of piezometers to collect groundwater samples may be approved by the Site Remediation Program provided they meet the monitor well construction requirements.

In all cases where wells are installed in oversize boreholes, the borehole diameter must be a minimum of four inches larger than the well casing diameter. For example, a borehole must be at least eight-inches in diameter if a four-inch well casing will be installed.

A.6.1.4.2 Well Construction Materials

Overburden monitor wells should be constructed with either PVC or stainless steel casing and screen. In general, PVC is acceptable for most applications. However, where free product is present and it is likely to cause failure of the well, use of PVC may not be appropriate since PVC can degrade in free product causing the well to collapse or the screen to fail. In this case, stainless steel should be used. However, stainless steel should not be used in highly corrosive waters since metals may leach from the stainless steel causing the detection of false positives in water samples analyzed for metals. In such waters, PVC should be used. Other construction materials (e.g., PTFE) must be approved by the SRP case/site manager or geologist prior to use.

Bedrock wells are typically constructed using carbon steel casing with the intake of the well being an open hole in the bedrock. In cases where the bedrock is friable, well casing and screen may be installed in the borehole of a bedrock well. Either PVC or stainless steel well casing and screen may be appropriate for installation in bedrock, depending on the type of contaminants present (see paragraph above). In this case, installation of an outer casing (double-cased well) may not be necessary, particularly where there is a thin overburden formation and the bedrock is shallow and instead, a single-cased well that is consistent with the Monitor Well Requirements for Unconsolidated Aquifers may be appropriate. However, the driller must submit a deviation request to the Bureau of Water Allocation that is consistent with N.J.A.C. 7:9D-2.8(a). If the borehole diameter is 6-inches, then the casing and screen diameter should be 2-inches.

A.6.1.4.3. Screen Length

The maximum length of well screen (or open borehole in bedrock wells) for monitor wells is 25 feet. The purpose of this limitation is to minimize the potential to cross-contaminate uncontaminated aquifers. In most cases, screen length should be minimized (e.g., 5 to 10 feet of screen) if sufficient well yield is available to allow sampling of the well. In cases where low-flow sampling is intended in newly installed monitor wells, the wells should be installed with no more than five feet of screen (see Section 6.9.2.2, *Low-Flow Purging and Sampling*).

In cases where a well will be used for groundwater recovery, injection, air sparging, soil vapor extraction or aquifer testing, construction of the well with more than 25 feet of screen or open borehole may be acceptable. However, approval must be obtained from the SRP case/site manager or geologist prior to installing such wells.

A.6.1.4.4 Screen Slot Size and Filter Pack Materials

Filter pack material should be clean silica sand which is sized according to the texture of the borehole materials from sieve analysis data. The uniformity coefficient of the filter pack materials should not exceed 2.5. The screen slot size should be selected to retain at least 90% of the filter pack material. No more than five feet of filter pack should be placed above the well screen. The top of the filter pack may be graded from coarser to finer (going upward) to minimize penetration of the overlying grout.

A.6.1.4.5 Grouting Materials

The annular space in wells must be sealed to prevent the borehole from acting as a conduit for vertical migration of contamination. Acceptable grouting materials are provided in N.J.A.C. 7:9D-2.9 and the required procedures for sealing the annular space of wells is specified in N.J.A.C. 7:9D-2.10. All grouting materials should be installed as slurry using a side-discharge tremie pipe in order to prevent invasion of the grout into the filter pack. Examples of material include Portland cement, high-grade bentonite and Portland cement/high-grade bentonite mixtures. *The installation of a bentonite seal above the filter pack using bentonite pellets is not permitted*. Proposals for their use must be submitted as a deviation request to BWA, pursuant to N.J.A.C. 7:9D-2.8(a).

A.6.1.4.6 Well Depth

Pursuant to the Technical Requirements for Site Remediation, groundwater contamination must be delineated both horizontally and vertically (see N.J.A.C. 7:26E-4.4(h)3i). This may require installation of wells in clusters at various depths (see also Multi-screened Wells below). The well clusters not only provide information on water quality with respect to depth but also provide information with respect to horizontal and vertical hydraulic gradients in the aquifers which is required to properly characterize contaminant fate and transport.

Special considerations may be necessary for the construction of deep wells compared to shallow wells. For example, deep wells installed with 2-inch-diameter PVC casing and screen may require the use of Schedule 80 (wall thickness 0.218 inches), rather than Schedule 40 (wall thickness 0.154 inches), PVC since it is more rigid.

A.6.1.4.7 Multi-Screened Wells

Where groundwater contamination is found to be present at depth, the use of multi-screened or multiple-level wells may provide information on the vertical extent of contamination. The installation of such wells must be performed as prescribed by the manufacturer and must first be approved by the Department, pursuant to N.J.A.C. 7:9D-2.8. Examples of such wells include the Waterloo Multilevel Groundwater Monitoring System® and the FLUTe® method. (This should not be construed to represent an official Department endorsement of these methods; this discussion is for informational purposes only.) Seals installed between well intake zones should be at least two feet thick.

In most cases, installation of well pairs (e.g., shallow and deep) and well clusters (e.g., shallow, intermediate and deep) may be more appropriate than installation of multi-screened wells since they use conventional well installation technology. No packers are used to separate sample ports; packers can fail or not seal properly.

Likewise, well clusters, where wells are installed in separate boreholes, may be more appropriate than well nests in which multiple wells share the same borehole. Grout is less likely to invade well intakes (screens) if the wells are installed in separate boreholes. Regardless of which method is used (i.e., well clusters versus well nests and mulit-screened wells), care must be taken to assure that any confining unit between aquifer zones is not breached without providing adequate protection of underlying/overlying aquifers (e.g., installing double casing and grout, etc.).

Disadvantages of multiple-level devices are: 1) it is difficult, if not impossible, to repair the device if clogging occurs, 2) it is difficult to prevent and/or evaluate sealant and packer leakage, 3) there is a potential for the sampling ports to be labeled or identified incorrectly, and 4) these installations are more expensive than single-level monitoring wells.

The FLUTe™ (Flexible Liner Underground Technologies, Ltd., see URL below) system involves the use of a flexible liner that can be used to temporarily seal a boring in unconsolidated sediments or bedrock wells. The liners can also be used to sample borings and wells at specific depths through dedicated tubing within the liners. In addition, vapor samples can be obtained in the unsaturated (vadose) zone. The liners can be installed in both vertical and horizontal wells.

The liner can also be coated with a material (e.g., hydrocarbon-detecting paste) that reacts with NAPL. The liner then can be installed through the interior of a cone penetrometer rod. Water is added to the inside of the liner causing the liner to dilate in the hole but not in the CPT rods, which are then removed. After the reaction with the NAPL occurs, the liner is removed from the hole and the NAPL stains and their depths are observed and recorded.

Use of the FLUTe™ method (http://www.flut.com/systems.htm) and multi-screened wells requires specific approval from the SRP case/site manager or geologist and from BWA. Specific approval for installing bedrock wells with more than 25 feet of open borehole must be obtained from both SRP and BWA. For boreholes left open for more than 48 hours, or that are deeper than 50 feet, a well drilling permit must be obtained from BWA; a well record and well abandonment report must also be provided to BWA.

A.6.1.4.8 Pre-Packed Well Screens

Pre-packed PVC well screens are manufactured with filter pack materials (silica sand) inside them or they can be filled with sand in the field. They may also have bentonite seals or a foam bridge, which seals the well and prevents water from above from entering the screen. They have been developed for use with direct-push samplers (see above). The purpose of the pre-packed screen is to reduce the turbidity of the water samples collected using the direct-push method. The pre-packed well screen is placed inside of the direct-push rods. Upon reaching the targeted sample depth, the rods are retrieved leaving the screen in the ground. The seal expands to allow collection of water from a discrete depth. The screens are typically 3/4, 1 1/4 or 2 inches in diameter and 2.5 to 5 feet long. As with any direct-push sampling method, care must be taken to assure that confining units are not breached and contaminants are not permitted to migrate downward into formerly uncontaminated portions of the aquifer.

A.6.1.4.9 Horizontal Wells

Horizontal wells must be installed by a New Jersey-licensed well driller who must obtain a well permit from BWA. All proposals for installation of horizontal wells must first be approved by the Department. Installation of horizontal wells may include well screens longer than 25 feet provided that appropriate justification is submitted to the Department. All proposals for installation of horizontal wells must include the purpose of the well (e.g., monitor well or recovery well), type of well (e.g., blind or continuous), depths of the well/screened intervals, proposed construction diagram, the method used to install and centralize the well casing and screen, the grouting procedures and the specific sampling method(s) that will be used.

A.6.1.4.10 Wells Used to Investigate LNAPL and DNAPL

Any well installed to detect floating product, or light, non-aqueous-phase liquid (LNAPL), must be screened across the water table. Any overburden well installed in either LNAPL or dense, non-aqueous-phase liquid (DNAPL) should be constructed of stainless steel if the NAPL has the potential to cause failure of a PVC well.

Wells installed to detect DNAPL must be constructed so that DNAPL can enter the well screen. N.J.A.C. 7:9D-2.4(c)1 states that the screened interval or the filter pack shall not extend across the interface of a confining layer and an aquifer. However, a well screened down to the top of a confining unit will not necessarily detect DNAPL present on the confining unit if the thickness of the DNAPL is not sufficient enough for it to enter the screen. Most well screens are not slotted down to the bottom of the screen; the lowest slot may be two or three inches above the bottom of the well. In addition, the bottom well cap also raises the well slots from the bottom of the well. For these reasons, the bottom one to two feet of the screen may extend into the confining unit in order to create a sump for the DNAPL to accumulate in, provided that specific approval is first obtained from the Site Remediation Program and the Bureau of Water Allocation for constructing wells in this manner, pursuant to N.J.A.C. 7:9D-2.8. Care must be taken to prevent the well from completely penetrating the confining unit.

Wells installed in bedrock must meet the construction requirements provided in this Appendix and in N.J.A.C. 7:9D-2.4. These requirements include drilling the borehole used to case off the overburden a minimum of 10 feet into competent bedrock. However, if DNAPL and/or dissolved contamination is suspected or likely to be present in the weathered bedrock, the ten-foot casing requirement will hide the DNAPL from detection. In this case, an overburden well (with casing and screen) should be installed in the weathered bedrock and an outer steel casing installed ten feet into bedrock would not be required. Likewise, if the weathered bedrock is found to be contaminated, a well may need to be installed within the upper 10 feet of competent bedrock. If the well will be constructed with an open hole in the bedrock, an outer steel casing should be installed in the top two feet of competent bedrock to case off the overburden and weathered bedrock aquifers. If casing and screen will be installed in the bedrock aquifer, then installation of the outer steel casing may not be required. In any event, specific approval must first be obtained from the BWA for constructing wells in these situations, pursuant to N.J.A.C. 7:9D-2.8.

A.6.1.4.11 Lysimeters

Contamination moving from the surface toward the water table passes through the vadose zone. Because the soil water in the vadose zone is under tension, it cannot flow into a well under gravity. If soil water needs to be sampled, it must be collected with a suction lysimeter.

A suction lysimeter is a porous cup located on the end of a hollow tube (Fetter, 1993). The tube can be PVC or stainless steel. The porous cup can be ceramic, nylon, TeflonÒ or stainless steel. A suction is applied to the hollow tube and held for a period of time. The flow of soil moisture to the porous cup can be slow, and it may be necessary to hold the vacuum overnight to supply a sufficient volume of water for chemical analysis.

Suction lysimeters are considered to be Category 5 wells, pursuant to N.J.A.C. 7:9D-2.1(a)5, and must be installed and decommissioned accordingly, pursuant to N.J.A.C.7:9D-2.6 and N.J.A.C. 7:9D-3, respectively.

A.6.1.5 Miscellaneous Well Construction Considerations

A.6.1.5.1 Well Development

In accordance with N.J.A.C. 7:9D-2.11(b) all well development or redevelopment work shall be performed by a licensed well driller of the proper class. The objective of a monitor well is to provide a representative sample of water as it exists in the formation. Therefore, well development must restore the area adjacent to the well to its indigenous condition by correcting damage done to the formation during the drilling process. Monitor well development is required to: remove drilling fluid residues remaining in the borehole or surrounding aquifer; remove imported drilling water lost to the aquifer during the drilling procedure; restore the hydraulic properties of the formation immediately surrounding the monitor well, and; sort the filter pack material to allow ground water to freely flow to the monitor well.

There are three primary factors that influence the development of a monitor well: 1) the type of geologic material the well is installed in, 2) the design and completion of the well, and 3) the type of drilling method employed to install the well (EPA, 1991). Any of these factors can affect the success of, and the level of effort needed during, well development.

Acceptable well development methods include: bailing, overpumping, mechanical surging, air-lift surging, and water jetting. The best methods involve surging water flow back and forth through the well screen to sort the filter pack materials (see Figure 6.9) (Driscoll, 1986). Pumping alone will tend to cause particles moving toward the well to “bridge” together or form blockages that restrict subsequent particulate movement. The best methods include bailing, pumping/overpumping/backwashing, and surging with a surge block or a combination of these methods. Following the use of these methods, the wells must be pumped to remove the fines from the wells. The use of chemicals (e.g., detergents, chlorine, acids, or other chemicals) to increase or restore the yield of monitor wells is not acceptable. However, their use in recovery and/or injection wells may be acceptable with prior approval from the Department.

Air-lift methods may be used to effectively develop wells installed in permeable formations. However, they may introduce air into the aquifer surrounding the monitor well, and this air has the potential for altering groundwater quality, particularly for volatile organics. For these reasons, air-lift methods should not be performed within a well screen unless the double-pipe method is used. Whenever an air compressor is used, an air filter should be used to filter out any entrained oil.

Overpumping involves pumping a well at a rate that substantially exceeds the rate that the formation can deliver water. This rate is usually much higher than the rate that will be induced during subsequent purging and sampling of the well. This higher rate causes rapid and effective migration of particulates toward the pumping well. However, overpumping alone does not effectively develop monitor wells since a surging action is needed to properly sort the filter pack and permit removal of particulates from the borehole. Where there is no backflow-prevention valve installed, the pump can be alternately started and stopped. This allows the column of water that is initially picked up by the pump to be alternately dropped and raised up in a surging action (backwashing). Also, overpumping of a monitor well during development may draw groundwater to the monitor well from considerable distances and draw groundwater of quality not representative of the immediate vicinity of the monitor well, especially in anisotropic and/or bedrock aquifers.

Well yields determined during the development of monitor wells and the well development method(s) used should be recorded on all well logs, well records and as-built construction diagrams. The well yields should be taken into consideration when designing a sampling program. Well development should not be performed until the day after (i.e., a minimum of eight hours after) the well has been installed. This will allow time for the cement grout to set prior to well development.

A.6.1.5.2 Maintenance of Wells

Over time wells may become silted up. This may be the result of poor well design (e.g., inappropriate filter pack materials or screen slot size) or cases where wells are installed in fine-grained sediments (e.g., silt). When this occurs, part of the well screen can no longer yield a sufficient volume of water for sampling and/or it may prevent water from the most contaminated zone from entering the well. This requires that the well be redeveloped. Acceptable well development methods are discussed above (see Well Development).

Wells may become damaged due to weather conditions, accidents or vandalism. A well maintenance program should be developed to assure that wells are properly maintained so that samples can be collected that are representative of aquifer conditions and to prevent contaminants at the ground surface from seeping into wells and contaminating groundwater. Periodic inspections should be performed to assure that caps are present and locked, concrete collars are not cracked or broken and that flush-mounted well boxes remain water tight (i.e., lid and gasket are present).

A.6.1.5.3 Well Decommissioning Requirements

All Category 3 monitor wells must be sealed upon abandonment using the methods specified at N.J.A.C. 7:9D-3.1 (general requirement for decommissioning all wells). A Well Abandonment Report must be submitted to BWA within 90 days of decommissioning a Category 3 well. All Category 5 wells and geotechnical borings must be sealed in accordance with N.J.A.C. 7:9D-3.4. Borings 25 feet or less in depth may be decommissioned by back-filling with cuttings, pursuant to N.J.A.C. 7:9D-3.4(b). All borings 25 feet or greater in depth must be decommissioned using an approved sealing material in accordance with N.J.A.C. 7:9D-3.1.

However, the Site Remediation Program also requires that where NAPL is present or is likely to be present and/or confining layers are or may be present, the borehole must be sealed with an acceptable grout (see N.J.A.C. 7:9D-3.1 for acceptable grouting materials). Where the boreholes are 25 feet or less in depth, and no NAPL is present and/or no confining layers have been breached, then the boreholes may be back-filled with native materials.

Upon sealing a monitor well or permitted boring, the New Jersey-licensed well driller of the proper class must submit a Well Abandonment Report to the Bureau of Water Allocation within 90 days of decommissioning the well pursuant to N.J.A.C. 7:9D-3.1(l).

A.6.1.5.4 Flush Mount Wells

In some circumstances (e.g., operating service station), it may be impractical to install wells with casing above the surface. In such situations, flush mounted wells may be installed. Flush mounted wells must be installed with road boxes specifically manufactured for wells. The road box must be of the type with bolt-down lids, waterproof and able to withstand vehicular traffic. The lid must be clearly labeled as a monitor well. The road box must be firmly anchored to, or embedded in, a concrete surface seal. The concrete seal must be sloped away from the box, providing drainage for water and easy vehicular traffic. The road box shall extend slightly above the surface (1-2 inches) to prevent pooling of water on the bolt-down lid.

By the nature of their design, flush-mounted well boxes cannot be locked from the outside. As such, flush-mounted well boxes must be completed with a lockable cap on the inner casing. This cap must be water-tight. No vent hole shall be drilled in the cap or casing. In addition, flush-mounted well boxes must be large enough to allow adequate room to install and remove the lock and cap from the inner casing. There must also be adequate room to secure the flush-mounted box lid with the inner cap locked in place (See Figure 6.11).

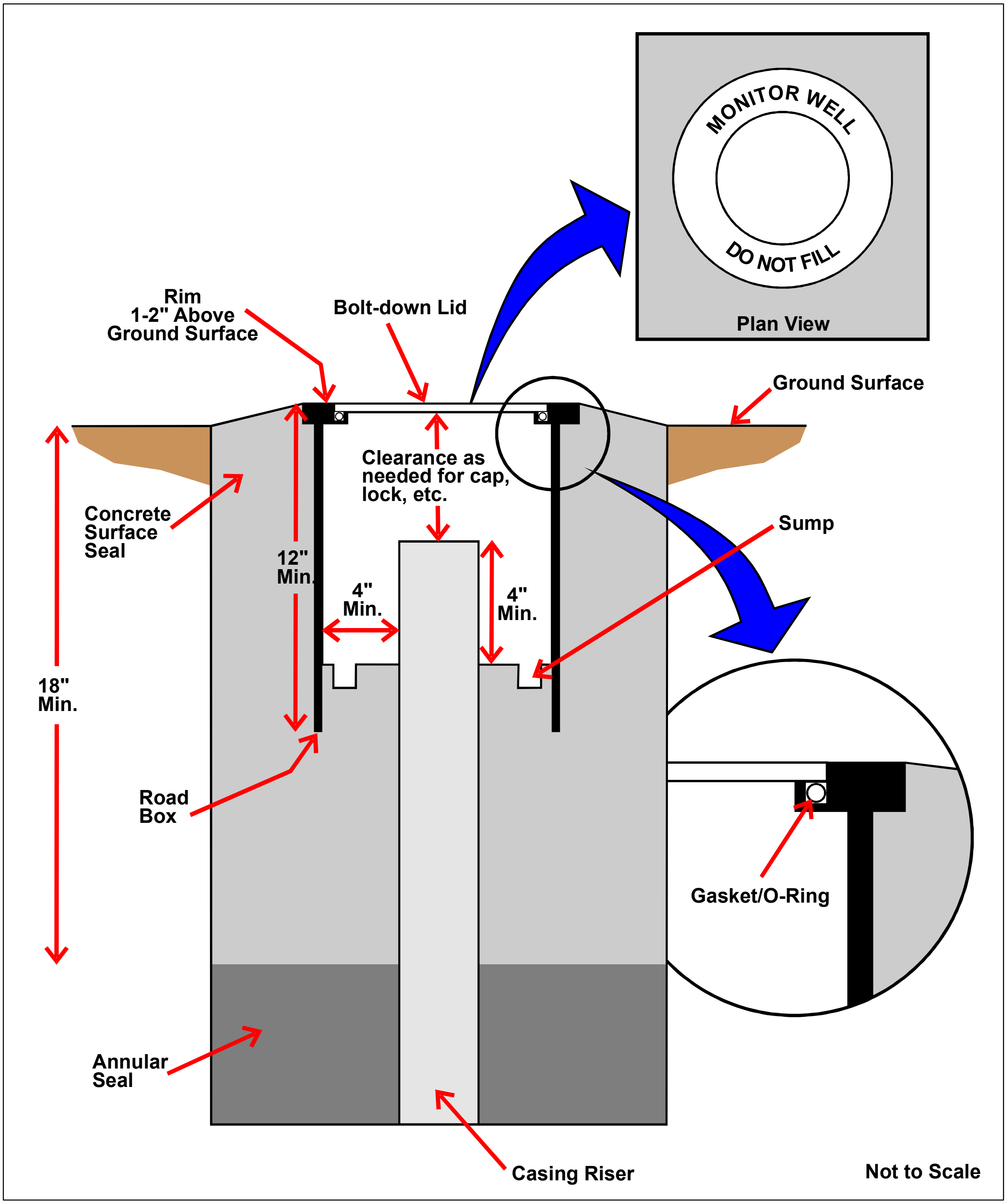

Figure 6.11 Typical Flush-Mount Completion. Illustration by M. Romanell.

Some wells may also be installed in below-grade vaults (e.g., recovery/extraction wells). The vaults must be watertight. Large vaults, whose maintenance would require someone to enter them, may be confined spaces and they would have to be entered with the appropriate precautions.

After installation of a well, a reference point must be marked on the top of the inner casing (with an indelible marker or by notching the top of the casing) for future water-level measurements. The well must be labeled with the owner's well number and Department's well permit number.

A.6.1.5.5 Subsurface and Overhead Utilities

It is the responsibility of the well driller to assure that well drilling activities do not encounter any subsurface or overhead utilities to avoid both disruption to utility services and for health and safety considerations. The driller must comply with all applicable OSHA requirements, pursuant to 29 CFR 1910, during well drilling operations and obtain utility markouts prior to starting drilling activities. At least three business days prior to commencing drilling activities, the driller should call 1-800-272-1000 or, from out of state, 1-908-232-1232. Well drillers should also be participating in a Medical Surveillance Program (MSP) and wear appropriate personal protective equipment.

Appendix 6.2 NJDEP Monitor Well Specifications for Bedrock, Unconsolidated and Confined Aquifers

A.6.2.1 Monitoring Well Requirements For Bedrock Formation (See Figure 6.12)

1. The construction of all monitoring wells shall be in accordance with the requirements of N.J.A.C. 7:9D-2.2 et seq.
2. The use of glues or solvents is prohibited in the installation of well screens, riser pipes and well casings.
3. The locking cap must be made of steel.
4. A New Jersey-licensed surveyor must survey top of the innermost casing (excluding cap) to the nearest 0.01 foot. The survey point shall be the highest point of the casing. If the casing is level, the survey point shall be established on the northern side of the casing. The survey point must be marked on each well via notching or indelible marker.
5. Wells should be developed to a turbid-free discharge.

Notice is Hereby Given of the Following:

The Department does not review well locations or depths to ascertain the presence of, or the potential for, damage to any pipeline, cable, or other structures.

The permittee (applicant) is solely responsible for the safety and adequacy of the design and construction of monitoring well(s) required by the Department.

The permittee (applicant) is solely responsible for any harm or damage to person or property which results from the construction or maintenance of any well; this provision is not intended to relieve third parties of any liabilities or responsibilities which are legally theirs.

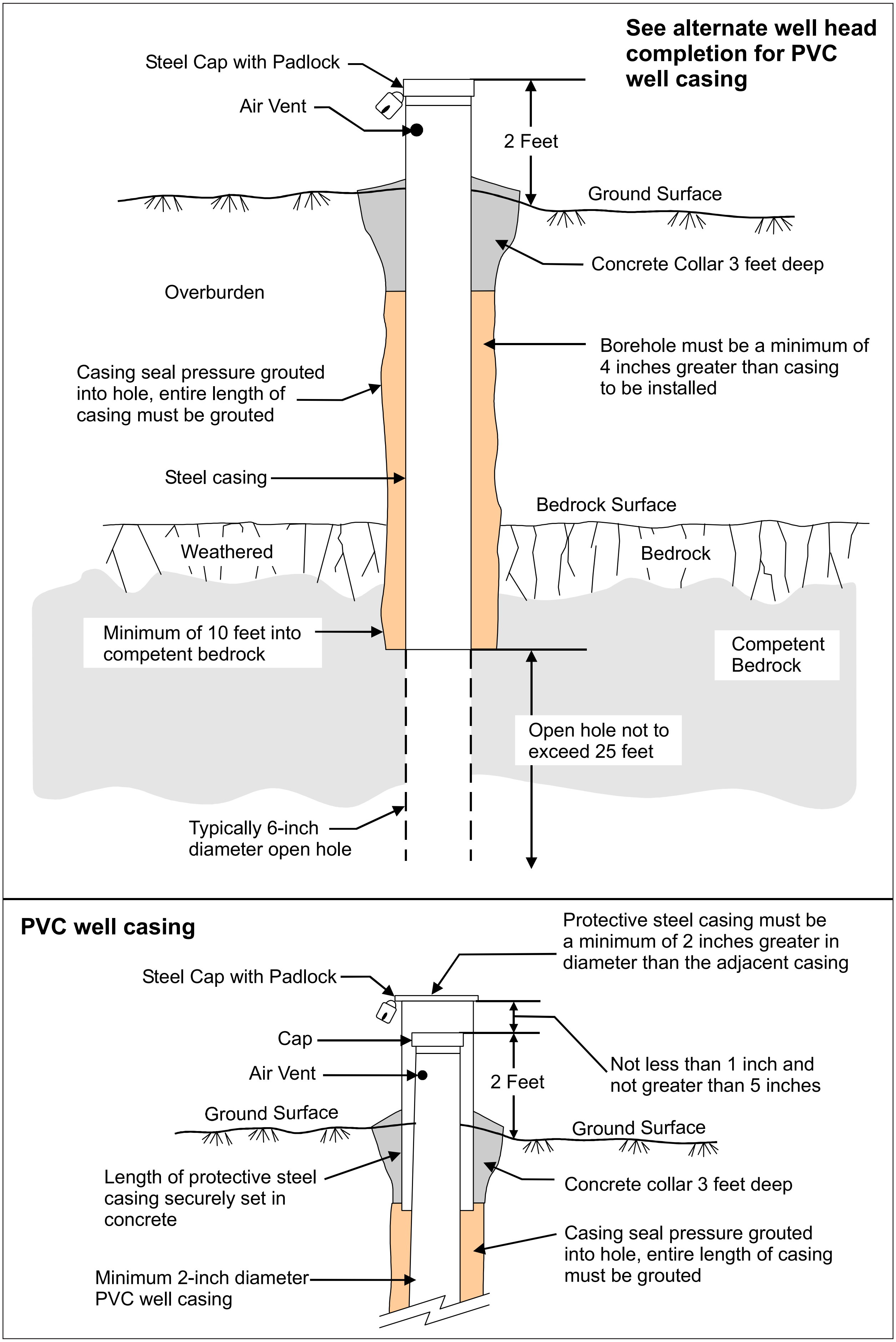

Figure 6.12 Bedrock Formation Well

A.6.2.2 Monitor Well Requirements For Unconsolidated Aquifers (See Figure 6.13)

1. The construction of all monitoring wells shall be in accordance with the requirements of N.J.A.C. 7:9D-2.2 et seq.
2. Minimum screen and riser pipe inner diameter is 2 inches.
3. The use of glues or solvents is prohibited in the installation of well screens, riser pipes and well casing.
4. In order to prevent any induced interconnection between the overburden/weathered bedrock and competent bedrock, the well screen shall not extend across the aforementioned interface.
5. Wells must have a filter pack installed.
6. When grouting the annular space directly above a filter pack, the grout should be discharged horizontally from the tremie pipe.
7. The locking cap must be made of steel.
8. A New Jersey-licensed surveyor must survey top of the innermost casing (excluding cap) to the nearest 0.01 foot. The survey point shall be the highest point of the casing. If the casing is level, the survey point shall be extablished on the northern side of the casing. The survey point must be marked on each well via notching or indelible marker.
9. Wells should be developed to a turbid-free discharge.

Notice is Hereby Given of the Following:

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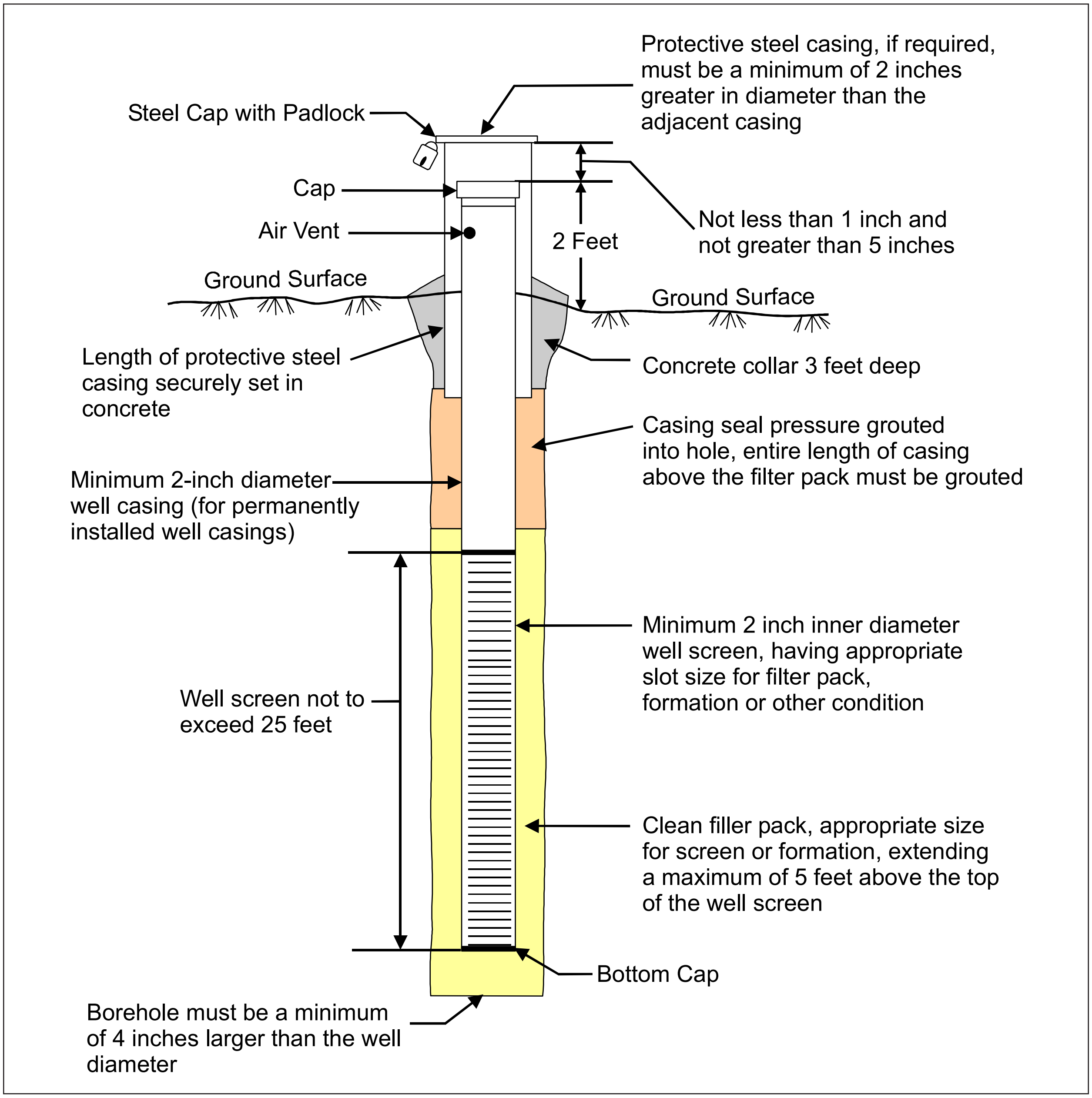

Figure 6.13 Unconsolidated Aquifer Well

A.6.2.3 Monitor Well Requirements For Confined Unconsolidated Aquifers (See Figure 6.14)

1. The construction of all monitoring wells shall be in accordance with the requirements of N.J.A.C. 7:9D-2.2 et seq.
2. Minimum screen and riser pipe inner diameter is 2 inches.
3. The use of glue or solvents is prohibited in the installation of well screens, riser pipes and well casing.
4. In order to prevent any induced interconnection between the overburden/weathered bedrock and competent bedrock, the well screen shall not extend across the aforementioned interface.
5. Wells must have a filter pack installed.
6. When grouting the annular space directly above a filter pack, the grout should be discharged horizontially from the tremie pipe.
7. The locking cap must be made of steel.
8. A New Jersey licensed surveyor must survey top of the innermost casing (excluding cap) to the nearest 0.01 foot. The survey point shall be the highest point of the casing. If the casing is level, the survey point shall be established on the northern side of the casing. The survey point must be marked on each well via notching or indelible marker.
9. Wells should be developed to a turbid-free discharge.

Notice is Hereby Given of the Following:

The Department does not review well locations or depths to ascertain the presence of, or the potential for, damage to any pipeline, cable, or other structures.

The permittee (applicant) is solely responsible for the safety and adequacy of the design and construction of monitoring well(s) required by the Department.

The permittee (applicant) is solely responsible for any harm or damage to person or property which results from the construction or maintenance of any well; this provision is not intended to relieve third parties of any liabilities or responsibilities which are legally theirs.

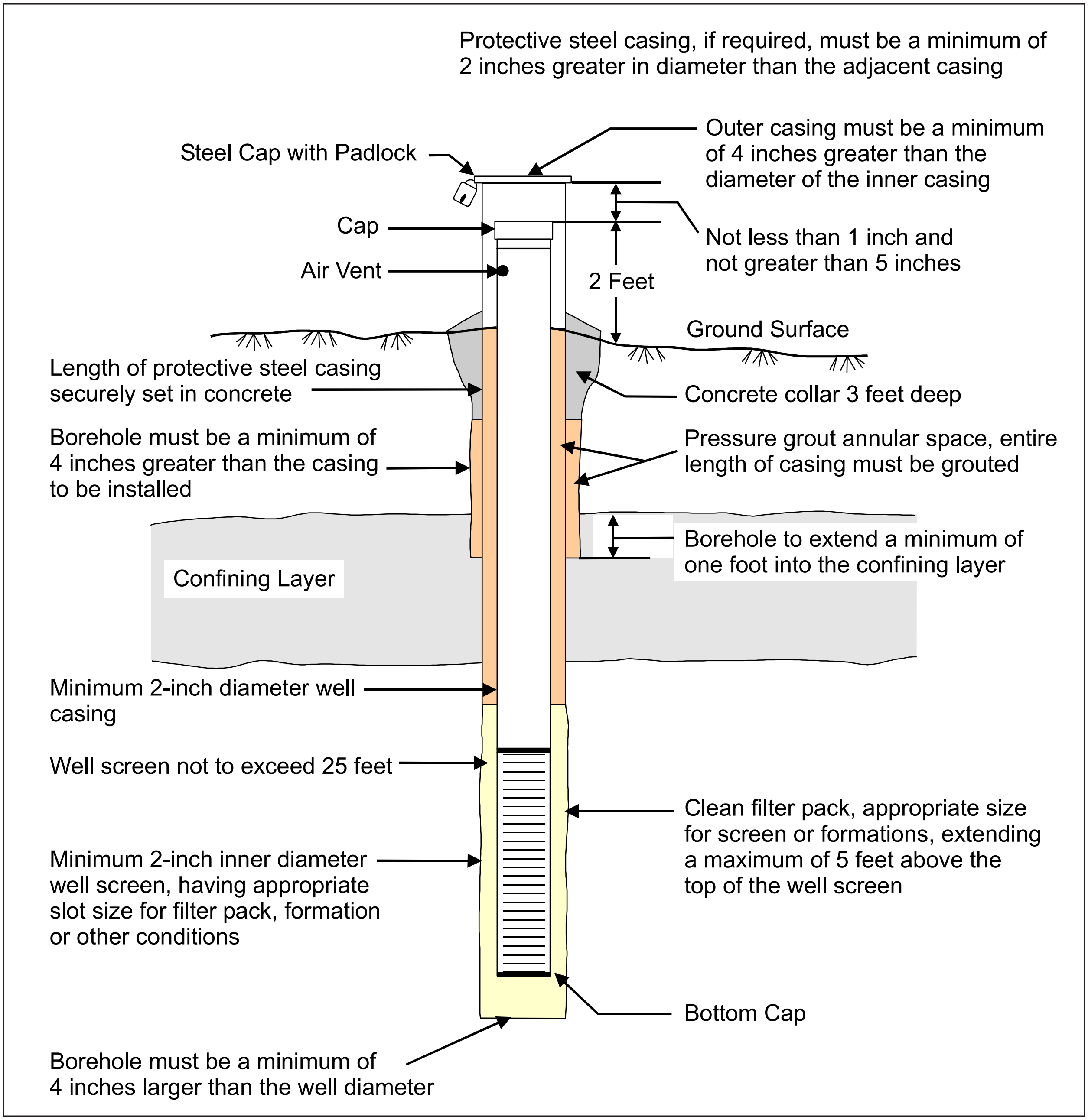

Figure 6.14 Confined Unconsolidated Aquifer Well